J. Perinat. Med.
14 (1986) 385

# Fetal electrocardiographic monitoring: past, present and future — a historical perspective

**E. Malcolm Symonds**

Department of Obstetrics and Gynecology, University Hospital, Nottingham, U.K.

## 1 Introduction

The original description of the fetal electrocardiogram was an extraordinary document. CREMER [1] in 1906 used silver electrodes attached to the abdominal wall and inserted in the vagina and demonstrated a primitive fetal signal with a string galvanometer. No one was particularly moved by this observation and one must remember that the clinical significance of heart rate did not come to the forefront until the 1950s. The subsequent progress of the subject has been very much linked with the development of suitable electrodes and advances in electronics. Nothing of any great significance occurred until 1936 when STRASSMAN [17] demonstrated the fetal ECG with standard maternal limb leads. He identified a window in the antenatal fetal ECG. The introduction of valve amplifiers increased sensitivity but there were considerable problems with noise and unstable baselines. No specific clinical value was described from these investigations. In 1953 SMYTH [15] performed an energy-frequency analysis of the fetal QRS complex and demonstrated a range of 20 to 40 cycles per second. SOUTHERN [16] described the relationship between ECG changes and oxygen saturation at the time of delivery and he demonstrated that fetal distress was associated with an increase in P wave amplitude, prolongation of the PR interval and depression of the ST segment. However, the ability to interpret these findings in relation to clinical practice was not sufficiently specific to enable fetal electrocardiography to be accepted into general clinical practice.

The first use of computer techniques in the analysis of the fetal electrocardiogram were documented by HON and LEE [4]. They achieved computer averaging by inserting a triggering signal after the R wave, recording the data on tape and then playing the tape in reverse to enable the signal to be used to initiate the averaging process. Clearly in real time this was not going to be useful.

In 1965 LARKS [6] introduced a new concept into fetal electrocardiography of estimating the

### Curriculum vitae

E. MALCOLM SYMONDS *is Foundation Professor of Obstetrics and Gynecology at the University of Nottingham. He has a major interest in perinatal medicine, and is at present President of the International Society for the Study of Hypertension in Pregnancy. He is a Fellow of the High Blood Pressure Council of the American Heart Association, and is also on Honorary Member of the Polish and Hungarian Obstetrical and Gynaecological Societies. He is co-editor of Clinical and Experimental Hypertension in Pregnancy — Part B.*

axis of the fetal heart by measuring the sum of the negative and positive deflections of the QRS complex in readings of the abdominal imaging of the fetal ECG. The estimation of electrical areas schowed a mean value of + 134$Pco_2$ with right heart preponderance. The abdominal fetal ECG was similar to lead II of the recorded electrocardiogram. The relationship between lead II of the neonatal electrocardiogram and the scalp electrode recording was also established by SYMONDS [18], but the relationship was not sufficiently concise to be of diagnostic value.

All of these findings were dependent on the examination of the realtionship between the R wave and S wave and were therefore associated with problems of spatial orientation because signals were either obtained through the maternal abdominal wall or by a single electrode attached to the head.

## 2 Fetal acid-base status and the electrocardiogram

The ability to identify components other than the QRS complex has been dependent on developing electrode systems that minimized electrical noise or filters that reduced external noise. The additional difficultiy in understanding the significance of ECG changes has been the problem of using suitable criteria in relation to outcome. Apgar scoring has always been unpredictable and at best a crude system of neonatal assessment. Probably the only hard criteria of asphyxia have been measured by the assessment of acid-base status, electrolyte values and lactate levels. In the early 1970s SYMONDS [19] published data in which fetal ECG signals were compared with simultaneous measurement of either scalp or cord blood acid-base measurements. This was the first attempt to systematically document ECG changes against acid-base measurements obtained at the time of ECG measurement. The difficulty about this study was the problem associated with hand processing of the data and of estimating the length of the QT segment when it was difficult to be certain of the limits of the T wave. Nevertheless, it is interesting to see that this study showed significant prolongation of the QT interval in the presence of a low cord venous blood pH when QT intervals were corrected for heart rate. QT prolongation was also associated with hyperkalemia and there was also T wave depression and inversion in the acidotic fetus. At that time, it was concluded that the overlap of values between normal and abnormal groups suggested limitation of these measurements for clinical usage. These studies underlined the need to develop a reliable system for the measurement of morphological and temporal changes in the ECG.

Heart rate was extensively exploited in the 1970s because of the relative ease of obtaining a QRS complex, but some work continued on the nature of the fetal electrocardiogram.

## 3 The development of computer analysis of the fetal ECG computer

There has always been one problem in using computer averaging techniques for all facets of ECG analysis. These systems cannot recognize or analyze cardiac arrhythmias. However, nearly all studies on the common fetal arrhythmias have failed to identify any association with asphyxia and apart from the occasional confusion created for the averaging process, the only other potential value of arrhythmia may rest with the diagnosis of congenital cardiac abnormalities.

In 1974 PARDI et al. [11] used a group averaging technique in analysis of the fetal ECG obtained by direct scalp electrode attachment and found that the PQ interval shortened during severe variable decelerations and that the P waves are often biphasic or absent. This group also demonstrated ST segment and T wave changes in 17 out of 35 cases with late decelerations. HIOKI [3] also studied ECG changes with group averaging techniques but the assessment of fetal distress was based entirely on fetal heart rate and ot on acid-base measurements. The data in this study suggested shortening of the ST segment and a reduction in T wave duration.

A series of animal studies in the last decade have helped to clarify the expected changes in the fetal ECG. MYERS [10] studied partial and total asphyxia in monkeys and stated that the change in the fetal ECG were variable and unreliable. YEH et al. [20] showed PR lengthening in the asphyxiated baboon fetus but also demonstrated elevated ST segment and increased T wave height. In 1975 ROSEN and KJELLMER [12] observed ST segment elevation and increased T wave height. These changes appeared before heart-rate alterations occurred. These workers have also established a strong linear correlation between ST segment and T wave changes and cardiac glycogen and creatinine phosphate levels.

These and other studies on fetal lambs by the same group have, of course, had the advantage of demonstrating the ECG with precordial leads and whilst at the recent FIGO congress, there was a presentation on direct fetal electrode application through the maternal abdominal wall in the human, the pattern has to be towards less invasion and not more.

GREEN et al. [2] studied the ST segment with a computer based averaging system triggered by the R wave and using chronically cannulated fetal lambs, also produced ST segment elevation in the presence of hypoxia.

The problem about all these observations has been the difficulty in analyzing data in real-time and of presenting the data in a form that can be read without difficulty. The Nottingham Project has attempted to achieve this objective and was started in 1973. The original system developed by SHEILD [13] and KIRK (see: [13]) in 1977 consisted of a data acquisition system including a method for signal storage followed by a data processing system using a Honeywell DDP 516 minicomputer. These techniques were subsequently advanced by MARVELL [7] and the further advancement of these techniques has included the development of software routines which have enabled FECG complex recognition, FECG complex enhancement and FECG complex measurement. Waveform assessment has been based on a continous "weighted sliding window" average, and the assessment is made every 15 seconds. This is a matter of choice and can be modified to shorter time intervals if required. Waveform time components are calculated from software routines developed by MARVELL and KIRK [8] in 1980 and modified by SMITH [14] in 1983. The 18 different parameters included in these studies are then presented in a digital or graphical form. The digital format records means and standard deviation. The analogue format is clearly much easier to "eyeball". It is now reasonable to say from the studies of JENKINS [5] that the asphyxiated human fetus follows a similar pattern to the animal models previously documented.

MARVELL [9] described a method establishing labor profiles by condensing data in presentation (figure 1). These profiles included reference to variability and the presence or absence of contractions. This is not a method that we

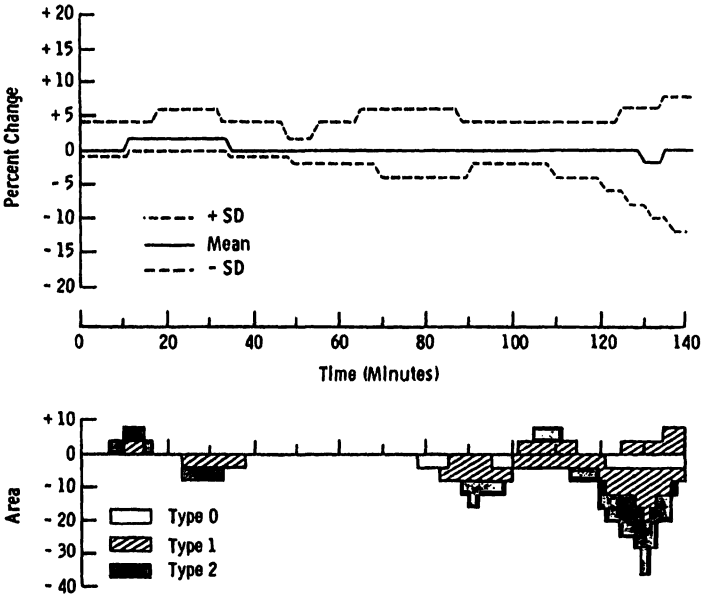


**Figure 1.** Average of labor profiles in 37 patients with normal outcome. The charts represent the last 140 minutes of labor.
The top graph shows the mean p wave area ± 1 SD for fetal heart rate (FHR).
The bottom graph displays the mean variability area profile for the parameter between contractions (Type 0) during contractions (Type 1) or up to 90 seconds after contractions (Type 2).
(From Marvell C et al, Br J Obstet Gynaecol 87 (1980) 876)

have pursued although it does appear to have considerable potential in understanding the pattern of change in labor.

## 4 The present status of real-time monitoring of the fetal ECG

The present situation is that it is now possible to measure any designated time constant from the fetal ECG. This can be achieved by considerable enhancement of the ECG signal. This means that the complete signal can be obtained from considerable background noise but with enhanced precision.

At this point in time, a considerable amount of work still needs to be undertaken to compare the relative discriminant abilities of ST segment, T wave characteristics and PR intervals against standard heart rate changes. Furthermore, this analysis needs to be widened to include a study of the correlation between variables as demonstrated by the studies on PR/RR. All such studies need to be quantified against acid base measurements. The establishment of normal ranges is necessary and yet it is likely that some of these intervals will not show aberrations until asphyxia is advanced.

## 5 The future advances in technique and interpretation

The future pathway for the application of fetal electrocardiography should follow two themes:

1) new methods of collecting the fetal signal
2) improved methods of data analysis and presentation

Studies that involve an appreciation of configuration of features other than the QRS complex can only be pursued in signals obtained by direct application of electrodes. PARDI and his colleagues have shown the value of analysis of the fetal QRS complex obtained from the antenatal recordings from abdominal leads (see: pp 371). This widens the potential field of application to antenatal as well as intrapartum assessment. If the techniques of signal recognition and enhancement can be applied to the abdominal signal, then it would be possible to measure P wave and T wave changes from the abdominal signal.

The second important avenue for development lies in the interpretation and analysis of the data. The lesson that we should have learnt from heart rate in labor and antenatal cardiotocography is the infinite capacity we have for self-delusion. Our ability to move from one technique of fetal assessment to another of no greater discriminant ability with a firm but unreasoned conviction that we have arrived at the promised land, appears to be infinite. The development of an intelligent terminal which can present complex data in a simplified and composite analysis should be an essential part of the next generation of fetal monitors. I do not believe it will be advisable to rely on individual interpretation.

New developments in fetal monitoring based on the ability to recognize the fetal ECG and in the use of intelligent terminals to interpret subtle and complex changes in the signals generated by the fetal heart should enhance our precision in recognizing significant changes in fetal acid-base blood gas status.

**Summary**

The first recording of the fetal electrocardiogram was described 80 years ago. Since that time only the peak of the QRS complex has been used in fetal monitoring for the measurement of fetal heart rate. Attempts to quantify changes in the configuration and time constants have been attempted over the last 30 years but despite the data obtained from animal experiments suggesting configurational changes in relation to hypoxia, the problems of electrical noise and signal distortion have restricted the application of these observations in the detection of fetal hypoxia in the human. Recent technical developments have now enabled continuous real time monitoring of the PR interval, heart rate and ST segment, and their findings and the interrelationships between different variables suggest a new approach to precise monitoring of the fetal state.

**Keywords:** Fetal acid base status, fetal electrocardiogram, labor profiles.

## Zusammenfassung

**Vergangenheit, Gegenwart und Zukunft der fetalen, elektrokardiographischen Überwachung — ein historischer Abriß**

Vor 80 Jahren erfolgte die erste Aufzeichnung eines fetalen Elektrokardiogramms. Seitdem wurde beim fetalen Monitoring lediglich der Peak des QRS-Komplexes zur Erfassung der fetalen Herzfrequenz benutzt. In den letzten 30 Jahren versuchte man, Veränderungen der Konfiguration und Zeitabschnitte quantitativ zu erfassen. Die Ergebnisse aus Tierversuchen ließen vermuten, daß Formveränderungen im EKG mit einer Hypoxie einhergehen. Probleme mit Hintergrundrauschen und Signalverzerrungen haben jedoch die Übertragung dieser Beobachtungen auf den Menschen zur Aufdeckung einer fetalen Hypoxie stark eingeschränkt. Der heutige Stand der technischen Entwicklung ermöglicht jetzt ein kontinuierliches Real-time-Monitoring des PR-Intervalls, der Herzfrequenz und der ST-Strecke. Die Ergebnisse weisen darauf hin, daß zwischen den unterschiedlichen Variablen Zusammehänge bestehen. Ihre Erfassung ermöglicht eine präzisere Überwachung des fetalen Zustands.


**Schlüsselwörter:** Fetales Elektrokardiogramm, fetaler Säure-Basen-Haushalt, Wehenprofil.


## Résumé

**Surveillance électrocardiographique du fœtus: passé, présent et futur — perspective historique**

Le premier enregistrement de l'électrocardiogramme fœtal a été décrit il y a 80 ans. Depuis on n'a utilisé que le pic des complexes QRS sur les enregistrements fœtaux pour mesurer le rythme cardiaque fœtal. Au cours des 30 dernières années on a essayé de quantifier les modifications de la configuration et des constantes temporelles, mais malgré les données obtenues grâce aux expérimentations animales qui suggèrent qu'il existe des modifications configurationelles en liaison avec l'hypoxie, l'application de ces observations pour la détection de l'hypoxie fœtale dans l'espèce humaine a été limitée par les problèmes du bruit de fond électrique et la distortion du signal. Les progrès techniques récents permettent actuellement une surveillance continue en temps réel de l'intervalle P.R., de la fréquence cardiaque et du segment S.T.; leurs résultats et les relations entre les différentes variables suggèrent une nouvelle approche de surveillance rigoureuse de l'état du fœtus.


**Mots-clés:** Electrocardiogramme fœtale, équilibre acido-basique fœtal, profils per partum.

## References


[1] Cremer M: Über die direkte Ableitung der Aktionsströme des menschlichen Herzens vom Oesophagus und über das Elektrokardiogramm des Fötus. MMW 53 (1906)

[2] Greene KR, GS Dawes, H Lilja, KG Rosen: Changes in the ST waveform of the fetal lamb electrocardiogram with hypoxia. Am J Obstet Gynecol 144 (1982) 950

[3] Hioki T: Averaged fetal electrocardiogram obtained by direct lead in fetal distress diagnosed by fetal heart rate patterns. Acta Obstet Gynecol Jpn 22 (1975) 162

[4] Hon EH, ST Lee: Noise reduction in fetal electrocardiography, II averaging techniques. Am J Obstet Gynecol 87 (1963) 1086

[5] Jenkins HML, EM Symonds, DL Kirk, PR Smith: Can fetal electrocardiography improve the prediction of fetal acidosis? Br J Obstet Gynaecol 93 (1986) 6

[6] Larks SD, GG Larks: The electrical axis of the fetal heart. A new criterion for fetal well-being or distress. Am J Obstet Gynecol 93 (1965) 975

[7] Marvell CJ: The normal condition in fetal electrocardiography, Ph. D. Thesis. University of Nottingham 1979

[8] Marvell CJ, DL Kirk: Use of microprocessor to stimulate precise electrocardiograms. J Biomed Eng 2 (1980) 61

[9] Marvell CJ, DL Kirk, HML Jenkins, EM Symonds: The use of labour profiles in assessing the behaviour of the fetal electrocardiogram. J Biomed Eng 2 (1980) 221

[10] Myers RE: Two patterns of perinatal brain damage and their conditions of occurrence. Am J Obstet Gynecol 112 (1972) 246

[11] Pardi G, E Tucci, A Uderzo, D Zanin: Fetal electrocardiogram changes in relation to fetal heart rate patterns during labour. Am J Obstet Gynecol 118 (1974) 245

[12] Rosen KG, I Kjellmer: Changes in the fetal heart rate and ECG during hypoxia. Acta Physiol Scand 93 (1975) 59

[13] Sheild J: Surveillance of asphyxia with fetal electrocardiogram, Ph. D. Thesis. University of Nottingham 1977

[14] SMITH PR: An advanced fetal monitoring system, Ph. D. Thesis. University of Nottingham 1983
[15] SMYTH CN: Experimental electrocardiography of the fetus. Lancet 6749 (1953) 1124
[16] SOUTHERN EM: Fetal anoxia and its possible relation to changes in the prenatal fetal electrocardiogram. Am J Obstet Gynecol 73 (1957) 233
[17] STRASSMAN EO: The fetal electrocardiogram in late pregnancy. Proc Staff Meetings, Mayo Clinic II (1936) 778
[18] SYMONDS EM: Vectorcardiography and acid-base balance in the human fetus. J Obstet Gynaecol Br Cwlth 79 (1972) 416
[19] SYMONDS EM: Configuration of the fetal electrocardiogram in relation to fetal acid-base balance and plasma electrolytes. J Obstet Gynaecol Br Cwlth 78 (1971) 957
[20] YEH M-N, HO MORISHIMA, WH NIEMANN, LS JAMES: Myocardial conduction defects in association with compression of the umbilical cord. Am J Obstet Gynecol 121 (1975) 951

Professor E. M. Symonds
Department of Obstetrics and Gynaecology
University Hospital
Nottingham, NG7 2UH, U.K.